Electronic Part Life Cycle Concepts and Obsolescence Forecasting

Rajeev Solomon, Peter Sandborn, and Michael Pecht

Abstract – **Obsolescence of electronic parts is a major contributor to the life cycle cost of long-field life systems such as avionics. A methodology to forecast life cycles of electronic parts is presented, in which both years to obsolescence and life cycle stages are predicted. The methodology embeds both market and technology factors based on the dynamic assessment of sales data. The predictions enabled from the models developed in this paper allow engineers to effectively manage the introduction and on-going use of long field-life products based on the projected life cycle of the parts incorporated into the products. Application of the methodology to integrated circuits is discussed and obsolescence predictions for DRAMs are demonstrated. The goal is to significantly reduce design iterations, inventory expenses, sustainment costs, and overall life cycle product costs.**

Index Terms – **Part life cycle, life cycle stages, parts obsolescence.**

I. Introduction

The electronics industry is one of the most dynamic sectors of the world economy. In the United States, this industry has grown at a rate three times that of the overall economy in the last ten years. The semiconductor industry is now number one in value-added to the U.S. economy, and the computer and consumer industry segments dwarf most other market segments. For example, Intel's market capitalization alone was higher than the three largest U.S. automakers combined [1].

The rapid growth of the electronics industry has spurred dramatic changes in the electronic parts, which comprise the products and systems that the public buys. Increases in speed, reductions in feature size and supply voltage, and changes in interconnection and packaging technologies are becoming events that occur nearly monthly. Consequently, many of the electronic parts that compose a product have a life cycle that is significantly shorter than the life cycle of the product. The part becomes obsolete when it is no longer manufactured, either because demand has dropped to low enough levels that it is not practical for manufacturers to continue to make it, or because the materials or technologies necessary to produce it are no longer available. The public's demand for products with increased warranties only makes the obsolescence problem worse. Therefore, unless the system being designed has a short life (manufacturing and field), or the product is the driving force behind the part's market (e.g., personnel computers driving the microprocessor market), there is a high likelihood of a life cycle mismatch between the parts and the product.

The life cycle mismatch problem requires that during design, engineers be cognizant of which parts will be available and which parts may be obsolete during a product's manufacturing run. This problem is prevalent in many avionics and military systems, where systems may encounter obsolescence problems before being fielded and often experience obsolescence problems during field life [2]. These problems are exacerbated by manufacturing that may take place over long periods of time, the high cost of system qualification or certification that make design refreshes using newer parts an extremely expensive undertaking. However, obsolescence problems are not the sole domain of avionics and military systems. Consumer products, such as pagers, are divided into two groups – 1) cutting edge (latest and greatest technology), and 2) workhorse, minimal feature set products (such as the pagers used to tell restaurant patrons that their table is ready). While the first set is unlikely to ever encounter obsolescence problems, the second set often does. Because OEMs require long lifetimes out of workhorse products, critical parts often become obsolete before the last product is manufactured.

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If a product requires a long application life, then an open architecture, or a parts obsolescence management strategy may be required. Many obsolescence mitigation approaches have been proposed and are being used. These approaches include [3], lifetime or last time buys (buying and storing enough parts to meet the system's forecasted lifetime requirements or requirements until a redesign is possible), part substitution (using a different part with identical or similar form fit and function), and redesign (upgrading the system to make use of newer parts). Several other mitigation approaches are also practical in some situations: aftermarket sources (third parties that continue to provide the part after it's manufacturer has obsoleted it), emulation (using parts with identical form fit and function that are fabricated using newer technologies), reclaim (using parts salvaged from other products), and uprating. Uprating is the process of using parts outside of their manufacturer specified environmental range (usually at higher temperatures than rated by the manufacturer) [4]. Uprating is becoming a common mitigation approach because the obsolete part is often the "MIL-SPEC" part while the commercial version of the part continues to exist. In some cases, the best obsolescence mitigation approach for OEMs who needs a broader environmental range part (often automotive, avionics, and military) is to "uprate" the commercial version of the part.

Earlier works have concentrated on understanding the product life cycle in terms of factors including product life cycle stages, product life, extension of product life, and product marketing issues [5]. The factor of obsolescence is not dwelt upon, but in the case of products, obsolescence may not be an issue depending on what the definition of a product is. For example, if a company's product is a sub-assembly, then obsolescence of that product, which may be due to obsolescence of a critical part, may affect the end-product life. Between part obsolescence and product obsolescence, part obsolescence needs more critical attention as the root of obsolescence at any product level, is the obsolescence of a part.

This paper reviews life cycle stages and then presents a methodology for forecasting the years to obsolescence for electronic parts. The prediction of obsolescence enables engineers to more effectively manage the introduction and on-going use of long field-life products based on the projected life cycle of the parts. The obsolescence prediction methodology is a critical element within risk-informed parts selection and management processes [6].

II. Life Cycle Stages

Most electronic parts pass through several life cycle stages corresponding to changes in part sales. Fig. 1 is a representative life cycle curve of units shipped per time, which depicts the six common life cycle part stages: introduction, growth, maturity (saturation), decline, and phase-out [7][1]. We include an additional category called Obsolescence. Table I and the proceeding discussion summarizes the characteristics of the stages of the part life cycle.

A. Introduction Stage

The introduction stage in the part life cycle is usually characterized by high production costs driven by recently incurred design costs and low yield, frequent modifications, low or unpredictable production volumes, and lack of specialized production equipment. Marketing costs, at this stage, may also be high. Early adopter customers who buy a part in its introductory stage tend to value performance over price.

B. Growth Stage

The growth stage is characterized by the part's market acceptance. Increased sales during this stage may justify the development and use of specialized equipment for production, which in turn improves economies of scale of production. Mass production, mass distribution, and mass marketing often bring about price reductions. This stage often consists of the largest number of competitors, as opportunity-seeking firms are attracted by the part's profit potential and, strategic acquisitions and mergers have not yet taken place.

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[1] Several additional phases have been proposed [8] including: Introduction Pending (prior to introduction), and splitting the Obsolescence stage into Last Shipment and Discontinued or Purged.

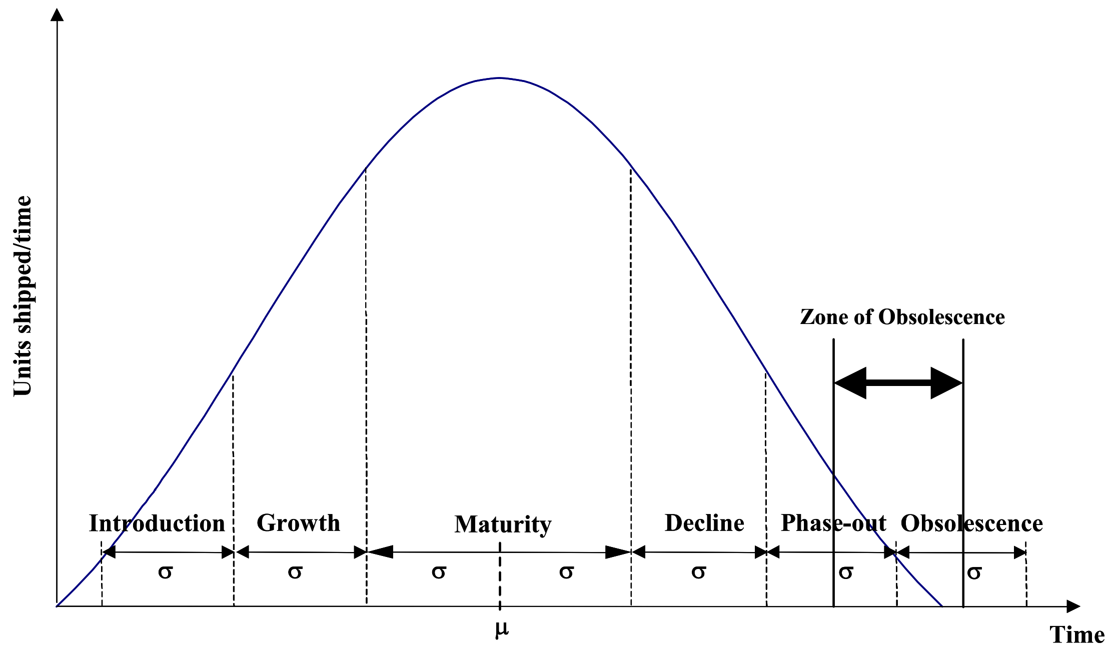

Fig. 1 Definitions for a standardized life cycle curve for a device/technology group. μ and σ represent curve fitting parameters discussed in Section III.

C. Maturity Stage

The maturity stage of the part life cycle is characterized by high-volume sales. Competitors with lower cost of production may enter the market, or domestic competitors may shift production facilities to less expensive locations to enable them to lower manufacturing costs. The 16M DRAM is an example of a mature part.

D. Decline Stage

The decline stage is characterized by decreasing demand and generally decreasing profit margin. Towards the end of the decline stage, only a few specialized manufacturers remain in the market. TTL logic ICs are examples of parts that have been available very late in this stage due to continued sales in the black and white television market.

Table I
Typical life cycle characteristics for the six generic stages of a part life cycle [9]

Characteristic	**Introduction**	**Growth**	**Maturity**	**Decline**	**Phase-out**	**Obsolescence**
Sales	Slow but increasing	Increasing rapidly	High	Decreasing	Lifetime buys may be offered	Sales only from aftermarket sources, if at all
Price	Highest	Declining	Low	Lowest	Low	Not applicable or very high if available from aftermarket sources
Usage	Low	Increasing	High	Decreasing	Decreasing	Low
Part modification	Periodic die shrinks, and possible mask changes	Periodic die shrinks	Periodic die shrinks	Few or none	None	None
Competitors	Few	High	High	Declining	Declining	Few
Manufacturer profit	Low	Increasing	High	Decreasing	Decreasing	Decreasing

E. Phase-out Stage

Phase-out occurs when the manufacturer sets a date when production of the part will stop. Generally, the manufacturer issues a discontinuance notice to customers, provides a last-time buy date, and suggests alternative parts or aftermarket manufacturers. As an example, on September 2, 1999 Texas Instruments (TI), Standard Linear and Logic Group announced the discontinuance of ULN2803A, a Darlington Transistor Array. TI stated that the product would be discontinued on September 2, 2000 [10] with the last (and non-cancelable) order date being March 2, 2000.

F. Discontinuance and Obsolescence

Discontinuance occurs when the manufacturer stops production of the part. The part may still be available in the market if the production line or part stocks were bought by an aftermarket source.

A part is obsolete when the technology that defines the part is no longer implemented. Thus, obsolescence occurs at a technology level, while discontinuance occurs at a part number or manufacturer specific level. Diode Transistor Logic (DTL) and Resistor Transistor Logic (RTL) parts are examples of obsoleted part technologies. National Semiconductor's military Quad SPST JFET Analog Switch in a ceramic DIP package is a discontinued part. The last time buy date for this part was December 7, 1999 [11]. A non-military part of the same functionality and technology remains available from National Semiconductor. In this case, the military part is discontinued, but the technology is not obsolete.

G. Special Cases of the Life Cycle Curve

Not all parts conform to the six life cycle stages presented in Fig. 1. Some parts undergo a false start and die out, or may be associated with a niche market. Some parts may also be revitalized after the decline stage. Other possibilities can also arise due to various economic, social, and environmental occurrences.

A false start typically suggests that a part starts out with a strong period of growth only to stall because of one or more of the following factors:

- introduction of a superior competing part
- improvement of a competing part

- identification of a problem associated with the part
- failure to reach the critical mass that allows economies of scale to be realized
- lack of a unique and compelling application for the part.

Niche parts generally have some unique applications and thus hold at a constant but relatively low sales level. An example is GaAs ICs, which found a niche market in telecommunications, military, and space applications.

Decline can often be delayed or reversed by revitalizing the original part. Defining new market segments, new applications, or creating a new image for the part, and thereby increasing the demand can cause revitalization.

III. LIFE CYCLE FORECASTING METHODOLOGY

The traditional method of life cycle forecasting is the "scorecard" approach, in which the life cycle stage of the part is determined from an array of technological attributes. Each attribute is given a life cycle code ranging from 1 through 6, and a corresponding weight. The overall stage for the part is determined by computing a simple weighted average of the life cycle codes for the attributes. The disadvantages of this approach are that it does not capture market trends accurately, because it relies on unquantifiable, technological attributes such as technology complexity and soft market attributes such as usage. This approach also makes the erroneous assumption that all ICs follow the same life cycle curve[2], makes the erroneous assumption that all life cycle stages are of the same length, and does not give a measure of confidence in the forecasting.

Another approach includes an "Availability Factor" method, which projects a "safe" usage window for a part. This approach uses market and technology factors to predict the obsolescence of devices with similar technology and market characteristics. This approach does not use the "life cycle curve" for the device, and cannot be used to determine the life cycle stage of the part.

This paper describes a fundamentally different approach to predicting life cycle stage and years to obsolescence based on modeling the life cycle curve for both devices and technology attributes. Fig. 2 outlines the methodology for life cycle forecasting.

[2] For example, consider the vastly different life cycle curves of the 741 op-amp and a DRAM. If only a life cycle stage is given as a prediction, an engineer who is selecting a part may be misled by a DRAM in a "mature" stage that has only two years until end of life, compared to a mature op-amp that has ten years until end of life. Hence knowledge of the complete life cycle is required when selecting a part.

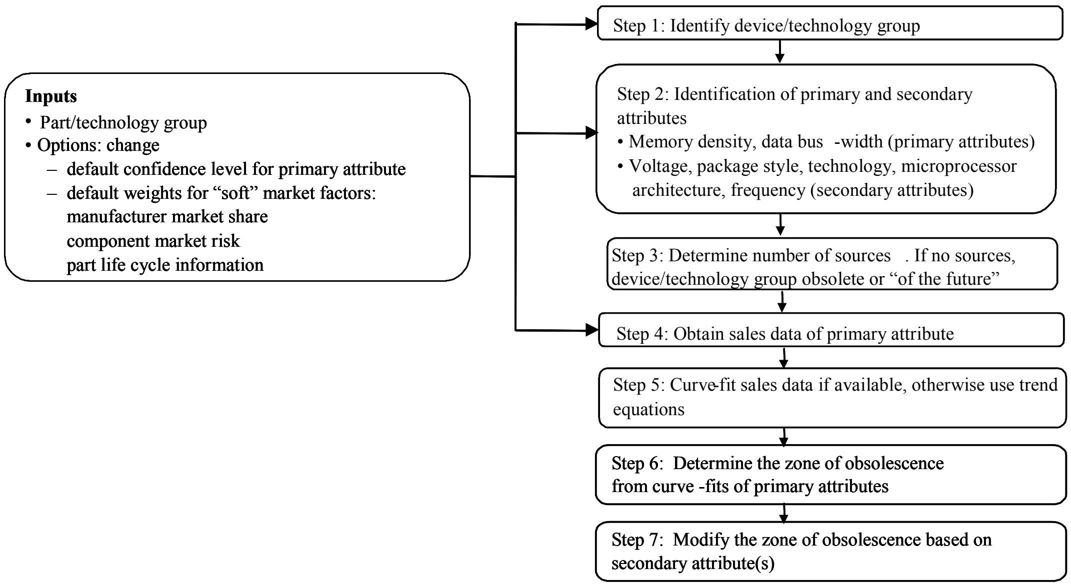

Figure 2: Life cycle forecasting methodology

Step 1: Identify device/technology group

A device/technology group is a family of devices that share common technological and functional characteristics, but may be produced by different manufacturers. For example, a device/technology group is the set of all 16M, 5V, SOP, EDO (technology characteristics) DRAMs (device functional characteristic) regardless of its manufacturer (Samsung, Micron, or Hyundai).

Step 2: Identify part primary and secondary attributes

A *primary attribute* is a characteristic that defines a device/technology group. For example, the primary attribute for a memory device is memory density. A *secondary attribute* is a characteristic of the device/technology group that can modify the range for years to obsolescence and/or life cycle stage of a device/technology group. For example, the secondary attributes for a memory device include package style and supply voltage.

Table II presents listings of primary and secondary attributes for major device classes. The primary and secondary attributes displayed in Table II are tracked by market research organizations, to help semiconductor manufacturers decide when to enter or leave a particular market.

Step 3: Determine number of sources

Determine the number of sources for the device. If no sources can be found, the device is either already obsolete or has not yet been manufactured.

Step 4: Obtain sales data of primary attribute of device/technology group

Sales data is a direct indicator of the life cycle of the device/technology group. The sales data may be in the form of number of units shipped, or if unit-sales data is not available, sales in market dollars or percentage market share may be used, if the total market does not increase appreciably over time. The sales data is available from market research organizations.

TABLE II
PRIMARY AND SECONDARY ATTRIBUTES FOR IC DEVICE CLASSES

Device Class	**Primary Attribute**	**Secondary Attribute(s)**
DRAM	Memory size	DRAM type (EDO, FPM, Synchronous, Rambus), package style (DIP, SOP, CC, PGA, QFP, MCM, other package styles[3]), voltage (5V, 3-5V, 3-3.5V, <3V)
SRAM	Memory size	SRAM type (no-cache, cache, synchronous, asynchronous, sync-burst), package style (DIP, SOP, CC, PGA, QFP, MCM, other package styles), voltage (5V, 3-5V, 3-3.5V, <3V)
Flash	Memory size	Package style (DIP, SOP, CC, PGA, QFP, MCM, other package styles), voltage (5V, 3-5V, 3-3.5V, <3V)
EPROM	Memory size	Package style (DIP, SOP, CC, PGA, QFP, MCM, other package styles), voltage (5V, 3-5V, 3-3.5V, <3V)
EEPROM	Memory size	Package style (DIP, SOP, CC, PGA, QFP, MCM, other package styles), voltage (5V, 3-5V, 3-3.5V, <3V)
Microcontrollers and DSPs	Data bus-width	Package style (DIP, SOP, CC, PGA, QFP, MCM, other package styles), voltage (5V, 3-5V, 3-3.5V, <3V)
Microprocessors	Data bus-width	Package style (DIP, SOP, CC, PGA, QFP, MCM, other package styles), voltage (5V, 3-5V, 3-3.5V, <3V), architecture (CISC, RISC), frequency
Logic devices	Logic family (HC, HCT, TTL, LSTTL, FAST/FASTr/..)	Package style (DIP, SOP, CC, PGA, QFP, MCM, other package styles), voltage (5V, 3-5V, 3-3.5V, <3V)
Analog devices	Special consumer	Technology (CMOS, BiCMOS, ECL, TTL, PMOS, NMOS), package style (DIP, SOP, CC, PGA, QFP, MCM, other package styles)
	Comparator	Package style (DIP, SOP, CC, PGA, QFP, MCM, other package styles)
	Voltage regulator	Package style (DIP, SOP, CC, PGA, QFP, MCM, other package styles), voltage (5V, 3-5V, 3-3.5V, <3V)
	Data conversion	Technology (CMOS, BiCMOS, ECL, TTL, PMOS, NMOS), package style (DIP, SOP, CC, PGA, QFP, MCM, other package styles)
	Interface	Technology (CMOS, BiCMOS, ECL, TTL, PMOS, NMOS), package style (DIP, SOP, CC, PGA, QFP, MCM, other package styles), voltage (5V, 3-5V, 3-3.5V, <3V)
	Other Analog	Package style (DIP, SOP, CC, PGA, QFP, MCM, other package styles), voltage (5V, 3-5V, 3-3.5V, <3V)
ASICs	Bipolar gate array, MOS gate array, linear array, bipolar PLD, MOS PLD, Bipolar standard cell, MOS standard cell, TTL ASIC	Package style (DIP, SOP, CC, PGA, QFP, MCM, other package styles), voltage (5V, 3-5V, 3-3.5V, <3V)

Step 5: Construct life cycle profile and determine life cycle profile parameters

Life cycle curves depict the number of units shipped, although sales of a device/technology group may be used if necessary. Each life cycle phase is defined in terms of its distance from the mean (μ) measured in standard deviations (σ) when the life cycle curve is fit with a Gaussian form. The zone of obsolescence is defined as the ordered pair: ($\mu + 2.5\sigma$ - p, $\mu + 3.5\sigma$ - p), where p is the present date, Fig. 1. This

[3] Includes Chip-Scale-Packages (CSPs), Ball-Grid-Array packages (BGA), Micro-Ball-Grid-Array (μBGA)

ordered pair gives the number of years from the present to the beginning and end of the window of obsolescence.

The life cycle profile is constructed by fitting the sales data of the primary attribute, a characteristic that is unique to, or defines, the device/technology group, to a life cycle forecasting distribution. Fig. 3 shows the life cycle curve of a 16M DRAM.

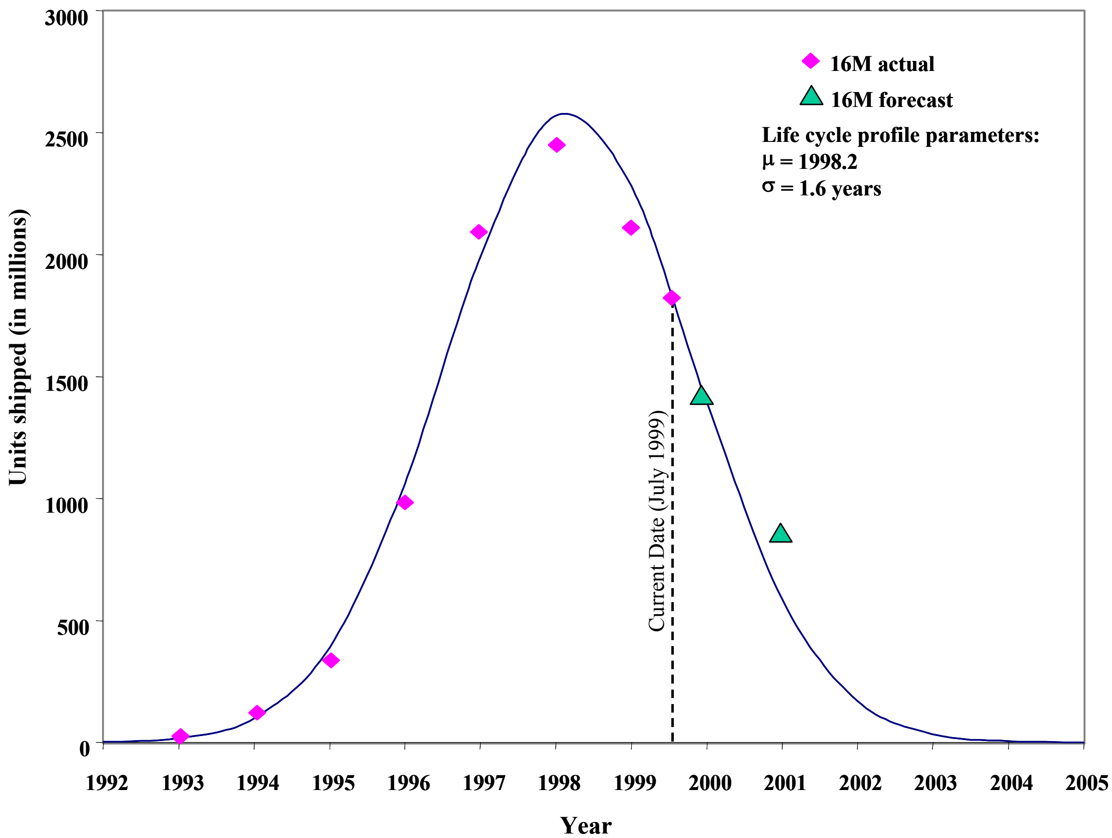

Fig. 3: Life cycle curve of a 16M DRAM. The dashed line marks the current date assumed for this example analysis. Data obtained from Cahner's In-Stat Group [12].

Gaussian distributions have been used by the Electronic Industries Association (EIA) as their standardized product life cycle (PLC) curve, and hence are well known and familiar to equipment suppliers [7]. The equation of the life cycle curve is

$$f(x) = ke^{\frac{-(x-\mu)^2}{2\sigma^2}} \tag{1}$$

where f (x) gives values for the sales revenue of the device/technology group (or number of units shipped, or the percentage market demand), x is the year, f(x) is defined by the mean μ, which denotes the point in time of the sales-peak of the curve, and the standard deviation σ. The factor k is the sales peak, the number of units shipped, or the percentage demand.

Trend equations are relationships of life cycle profile parameters (μ and σ for Gaussian distributions) with the primary attribute. Fig. 4 shows a sample trend curve for μ versus DRAM memory size. If the year of peak sales and the year of introduction are known, the time interval between them is defined to be 3σ, the standard deviation of a Gaussian distribution. Hence, σ can be computed and used as a first order estimate for forecasting. Fig. 5 shows a sample trend curve for σ versus DRAM memory size trend.

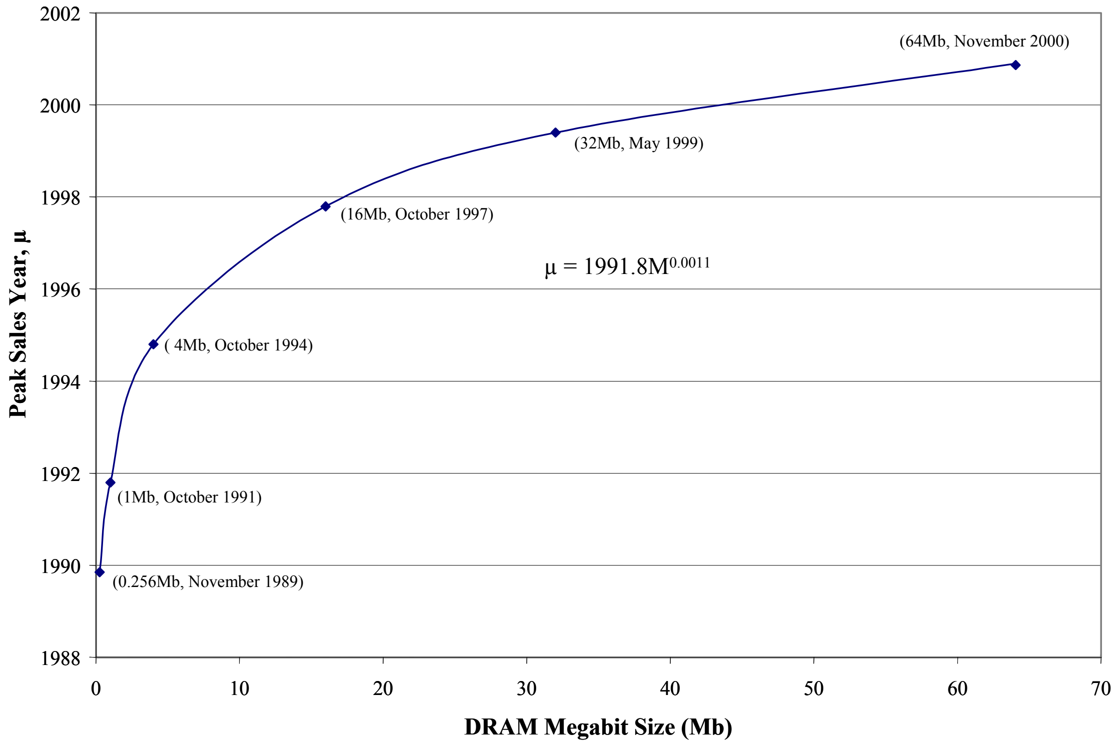

Fig. 4: Mean versus DRAM memory size; Curve fit is based on the trend equation μ = 1991.8M0.0011 where μ is the year of peak sales and M is the corresponding memory size. Data obtained from Cahner's In-Stat Group [12].

Step 6: Determine the zone of obsolescence from the life cycle profile of the primary attribute

The zone of obsolescence refers to a period of time in which the device/technology group has high probability of being obsoleted. The zone of obsolescence is given by the ordered pair: (μ+ 2.5σ - p,μ + 3.5σ - p) where p is the present date. For the 16M DRAM shown in Fig. 3, the zone of obsolescence is 2.7 to 4.3 years.

Life cycle stages are determined by dividing the life cycle curve for the primary attribute into introduction (μ- 3σ,μ - 2σ), growth (μ- 2σ,μ -σ), maturity (μ-σ,μ+σ), decline (μ+σ,μ+2σ), and phase out (μ+2σ,μ +3σ), Fig. 1. Fig. 6 depicts the life cycle stage and years to obsolescence of a 16M DRAM.

Step 7: Modify the zone of obsolescence based on secondary attribute(s)

The life cycle profile of the device/technology group may require modification by secondary attributes. If the years to obsolescence for any of the secondary attributes fall within the life span (± 3σ years) of the main attribute, the years to obsolescence for the generic device will be modified. The algorithm is summarized in Table III, where the secondary attributes are denoted by j, with μ_j and σ_j denoting the mean and standard deviation of the secondary attribute. The ordered pair (a_{min}, b_{min}) that is the smallest in numeric value among the remaining ordered pairs (a,b) obtained from the conditions given in Table III is the modified zone of obsolescence. Table IV depicts the application of the algorithm presented in Table III to evaluate the zone of obsolescence (the span of time during which the part is vulnerable to obsolescence) of a 16M, EDO, 5V, SOP DRAM. Fig. 7 shows the shift in the life cycle profile of the 16M DRAM resulting from the two secondary attributes.

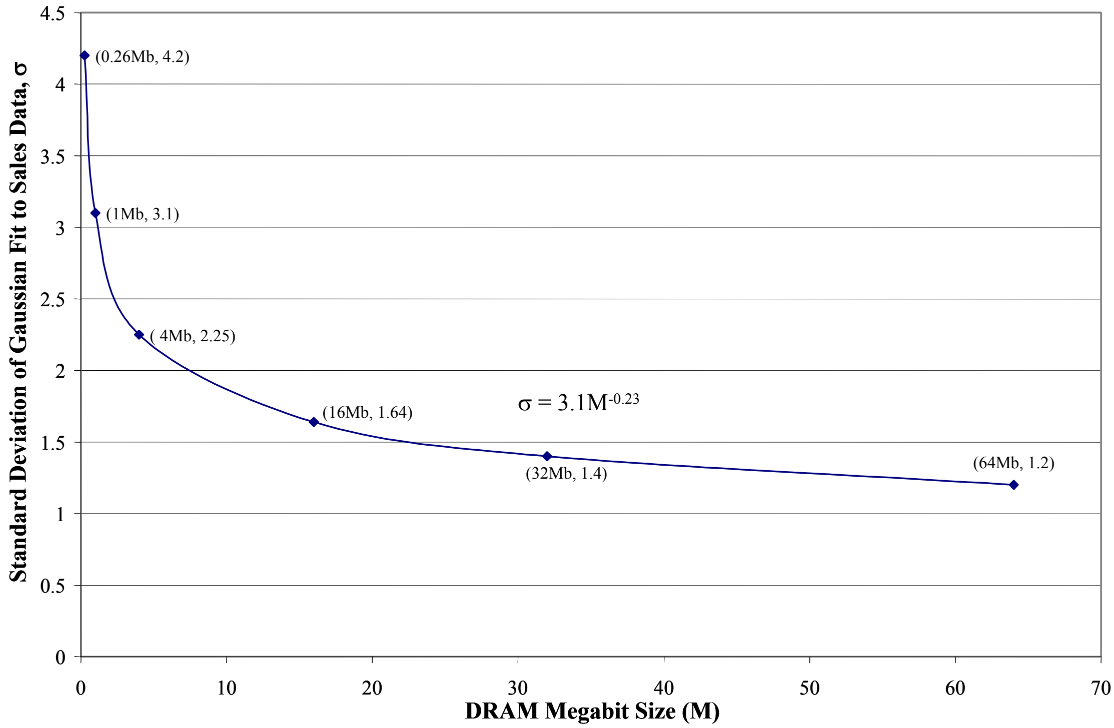

Fig. 5: Standard deviation s versus DRAM size; Curve fit is based on the trend equation$\sigma = 3.1M^{-0.23}$ where σ is the standard deviation and M is the corresponding memory size. Data obtained from Cahner's In-Stat Group [12].

TABLE III
ALGORITHM FOR CHOOSING A ZONE FOR THE YEARS TO OBSOLESCENCE FROM MODIFYING ATTRIBUTES

Condition	**Modified zone of obsolescence (a,b)**
$\mu_j + 3.5\sigma_j - p < \mu + 2.5\sigma - p$	$(\mu_j + 2.5\sigma_j - p, \mu_j + 3.5\sigma_j - p)$
$\mu + 2.5\sigma - p \leq \mu_j + 3.5\sigma_j - p \leq \mu + 3.5\sigma - p$	(min $[\mu + 2.5\sigma - p, \mu_j + 2.5\sigma_j - p]$, min $[\mu + 3.5\sigma - p, \mu_j + 3.5\sigma_j - p]$)
$\mu_j + 3.5\sigma_j - p > \mu + 3.5\sigma - p$	(min $[\mu_j + 2.5\sigma_i - p, \mu + 2.5\sigma - p]$, $\mu + 3.5\sigma - p$)

TABLE IV
CASE STUDY: MODIFIED ZONE OF OBSOLESCENCE OF A 16M, EDO, 5V, SOP DRAM

Attribute	**Zone of obsolescence (years)**	**Modified zone of obsolescence (years)**
Memory density (16M)	(2.7, 4.3)	-
DRAM type (EDO)	(2.2, 3.8)	-
Voltage (5V)	(1.3, 5.3)	(1.3, 3.8)
Package style (SOP)	(13.7, 18.9)	-

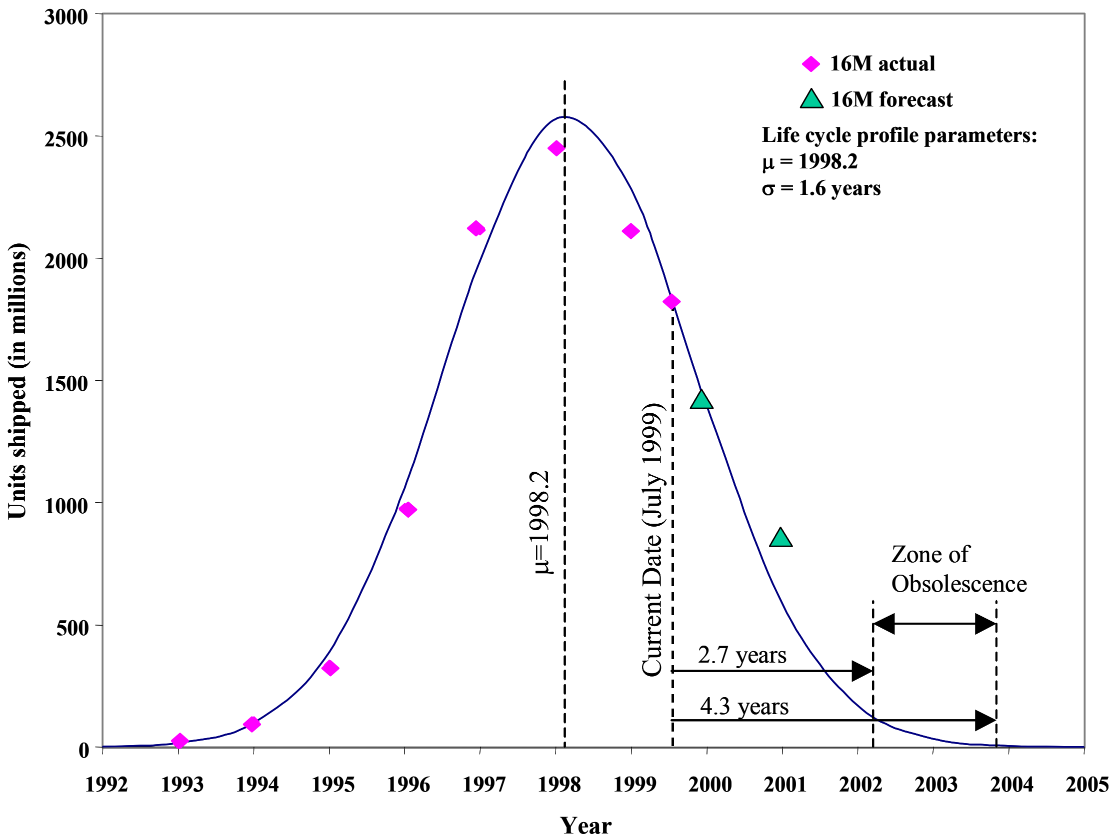

Fig. 6: Zone of obsolescence and life cycles for a 16M DRAM. Data obtained from Cahner's In-Stat Group [12]

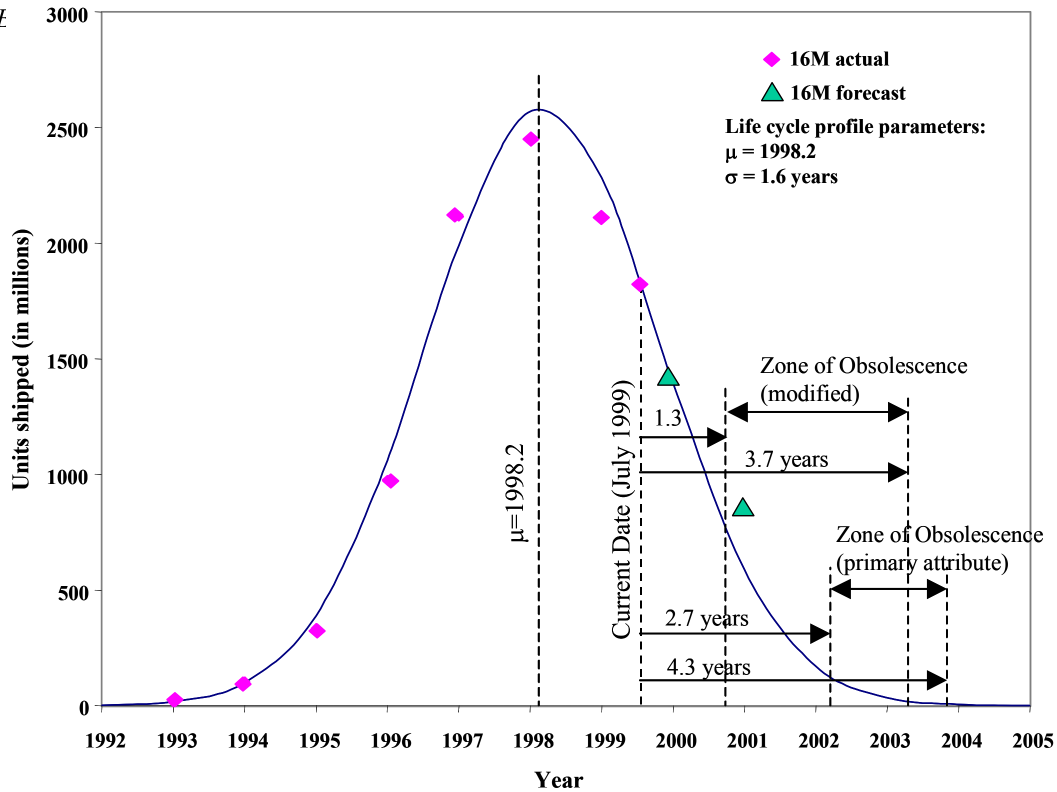

Fig. 7: Life cycle profile of a 16M DRAM. The decrease in decline period from 2.7 to 1.3 years due to effect of secondary attributes. Data obtained from Cahner's In-Stat Group [12].

IV. DISCUSSION

There are some *market factors* that are manufacturer and application-specific, which should be considered as an additional risk assessment associated with using a part. Any end-application that experiences growth encourages demand for the parts that go into its manufacture, which may result in a component market risk. For example, a strong growth in the demand for cellular phones has led to strong growth in the flash memory and EEPROM markets. The manufacturers having significant market share and profitability have a reduced probability of leaving the market. For example, it is highly improbable that Intel will quit the microprocessor market, as it controls over 80% market share, and microprocessors represent Intel's core competency. The number of sources device/technology group may be a risk factor especially when looking at alternatives. However:

- Many sources do not necessarily infer health (for example: the 256K 5V, DIP asynchronous SRAM is currently manufactured by 9 manufacturers; however the device/technology group is being obsoleted by manufacturers who are replacing the device with SRAMs of the same functionality, but in newer package styles and lower voltages).

- Only a few sources may suggest that the manufacturers still in business command most of the market share (for example: some aftermarket manufacturers continue to manufacture families of TTL logic even after the original manufacturers have discontinued their product lines).

- A big market player quitting the business does not necessarily mean "death" of the device/technology group. Manufacturers may decide to discontinue a product line for a host of business reasons, which may not have much to do with device/technology obsolescence. This occurrence is especially true in the "volatile" memory market. For example: Intel quit the memory market and focused on their core competency: microprocessors. Texas

Instruments, in September 1998, decided to sell off its entire memory line to Micron, and focus on DSPs, which is their core competency. This does not mean that memory market is "dying out".

V. SUMMARY

An electronic part usually advances through six stages: introduction, growth, maturity, decline, phase-out, and discontinuance. The part life cycle curves provide a basis for part analysis and forecasts. The part life cycle sales curve can be used to develop forecasts and predict life cycles, and plan for system redesigns and periodic upgrades accordingly.

Engineers must be aware of the part life cycles, otherwise, an engineer can end up with a product, whose parts are not available, which cannot perform as intended, cannot be assembled, and cannot be maintained without high life cycle costs. While technological advances continue to fuel product development, engineering decisions regarding when and how a new part will be used, and the associated risks traded-off with a new part and technology, differentiates the winning from the losing products.

The life cycle forecasting model presented in this paper:

- Captures market trends by identifying a set of quantifiable market and technological attributes (such as memory density, device supply voltage, memory device type, package style) that govern the growth and demise of device/technology groups,

- Computes both years to obsolescence and life cycle stage, based on statistical analysis of sales data for the market and technology attributes for the device/technology group,

- Computes an overall risk factor associated with a specific part number by implementing market factors, such as component risk, manufacturer market share, and part life cycle information.

The impact of the aftermarket is not accounted for in the life cycle curve approach. However, this is more of a "sourcing/availability" issue than a device/technology obsolescence issue. Aftermarket sources continue to manufacture the device long after the original manufacturers have obsoleted the actual device/technology groups. Equipment suppliers often build "special" relationships with aftermarket sources, sunset distributors, and GEM[4] sources (such as Sarnoff) to ensure continued availability.

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REFERENCES

1. B. Foucher, R. Kennedy, N. Kelkar, Y. Ranade, A. Govind, W. Blake, A. Mathur, and R. Solomon, "Why a new parts selection and management program?" *IEEE Transactions on Components, Packaging and Manufacturing Technology, Part A*, vol. 21, no. 2, pp. 375-382, June 1998.

[4] GEM is the acronym for Generalized Emulation of Microcircuits. Emulation is an obsolescence mitigation strategy, where the unavailable electronic parts are remanufactured using information gathered from sources such as data sheets, and test vectors.

2. A. Bumbalough, "USAF manufacturing technology's initiative on electronics parts obsolescence management," in *Proceedings of 44th International SAMPE Symposium*, pp. 2044-2051, May 1999.
3. R. C. Stogdill, "Dealing with obsolete parts," *IEEE Design & Test of Computers*, vol. 16, no. 2, pp. 17-25, April-June 1999.
4. M. Wright, D. Humphrey, and P. McCluskey, "Uprating electronic components for use outside their temperature specification limits," *IEEE Trans. on Components, Packaging, and Manufacturing Technology, Part A*, vol. 20, no. 2, pp. 252-256, June 1997.
5. Levitt, T., " Exploit the Product Life Cycle," The Harvard Business Review, Nov – Dec, 1965.
6. M Jackson, P. Sandborn, M. Pecht, C. Hemens-Davis, and P. Audette, "A risk-informed methodology for parts selection and management," *Quality and Reliability Engineering International*, vol. 15, pp. 261-271, 1999.
7. "Product Life Cycle Data Model," *American Standard ANSI/EIA-724*, September 19, 1997.
8. E. Sherwood, Proposal to EIA, "Product Life Cycle (PLC) Code Definitions and Applications," Motorola, Inc., February 7, 2000.
9. M. Pecht and D. Das, "The Electronic Part Life Cycle," *IEEE Transactions on Components and Packaging Technologies*, vol. 23, no. 1, pp. 190-193, March 2000.
10. Texas Instruments, 1999 Standard Linear and Logic Product Withdrawal Device List, September 2, 1999.
11. National Semiconductor, "Product Folder LF11331," available at http://www.national.com/pf/LF/LF11331.html as of March 28, 2000.
12. Karls, J., Dickens, H., and Shon-Roy, L., *Status 1998, A Report on the Integrated Circuit Industry*, ICE, Scottsdale, Arizona, 1998.